Foreseeing and Active-Suppression of Anomalous Discharge in Plasma Processing Equipment by *In-situ* Monitoring of Plasma State Using Viewing Port Probe

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Abstract – We demonstrate for the first time the foreseeing and active suppression of anomalous discharge in a plasma processing equipment. The foreseeing of anomalous discharge is realized by monitoring plasma state using a newly developed viewing-port probe. We have found that a foreseeing signal indicating a slight change in plasma potential appears prior to the occurrence of the anomalous discharge. The time interval between the foreseeing signal and the occurrence of the abnormal discharge is several tens millisecond, which allows to build-up a electric system to control the plasma state. The active suppression of anomalous discharge is demonstrated using a reactive ion-etching system by controlling the applied voltage of electrostatic chuck of wafer stage.

INTRODUCTION

Plasma processing, such as dry etching and ashing, is absolutely imperative in advanced large-scale-integrated circuit (LSI) manufacturing. Equipment for plasma processing, however, has a common problem, namely, anomalous electric discharge which occurs in a plasma chamber. The anomalous discharge occurs suddenly at a part of the process chamber components. Although the anomalous discharge lasts only for a few μs and expenses only a small energy, it significantly reduces the yield of LSI because it generates a number of particulate, electrically and/or physically damages devices on the semiconductor wafer, induces unstable plasma. It is, therefore, invaluable to make it possible to foresee the occurrence of anomalous discharge and actively suppress the anomalous discharge without disturbing the plasma processing of wafers.

We have created two sensors which are able to detect the occurrence of the abnormal discharge. One is the AE (acoustic emission) sensor which detects the acoustic waves emitted from the point where the anomalous discharge occurred [1]. The anomalous discharge could be monitored by detecting the acoustic waves using the AE sensor both in direct-current (DC) and radio-frequency (RF) plasma equipment. The monitoring method by detecting the supersonic waves signal accompanied by the anomalous discharge does not exert the influence on plasma and is independent of the plasma generation method. The second one is the sensor which we designated as viewing port (VP) probe which detects the change in charge build-up at the glass surface of a viewing port [2]. The VP probe electrically monitors the plasma state which changes with the generation of abnormal plasma state, while the AE sensor physically monitors the occurrence of abnormal discharge.

These two sensors have been shown to be very effective to monitor the occurrence of the abnormal discharge. The VP probe offers highly sensitive monitoring of the occurrence of abnormal discharge. The AE sensor is able not only to monitor the occurrence of abnormal discharge but also to search the position of point where the abnormal discharge took place by analyzing the acoustic signals detected by multiple AE sensors attached at different place on the plasma equipment. Therefore the combination of these two monitors gives very useful information of the occurrence of abnormal discharge.

The next challenge is to make it possible to foresee and actively suppress the abnormal discharge. [3] We have found that a small signal is detected by the VP probe prior to the occurrence of abnormal discharge. This foreseeing signal is small compared with the signal of abnormal discharge but definitely appeared. By utilizing this signal as a trigger, we have recently succeeded in developing a system which actively suppresses the abnormal discharge. In this paper we report the detection of the foreseeing signal and the active suppression. The active suppression of anomalous discharge is demonstrated by using a reactive ion etching (RIE) system by controlling the voltage applied to the electrostatic chuck of wafer stage.

EXPERIMENTAL

The experimental setup for detection of anomalous discharge using the AE sensor and VP probe is schematically shown in Figure 1. The processing equipment used was a reactive ion etching (RIE) system, which is parallel-plate-type. The VP probe, which detects

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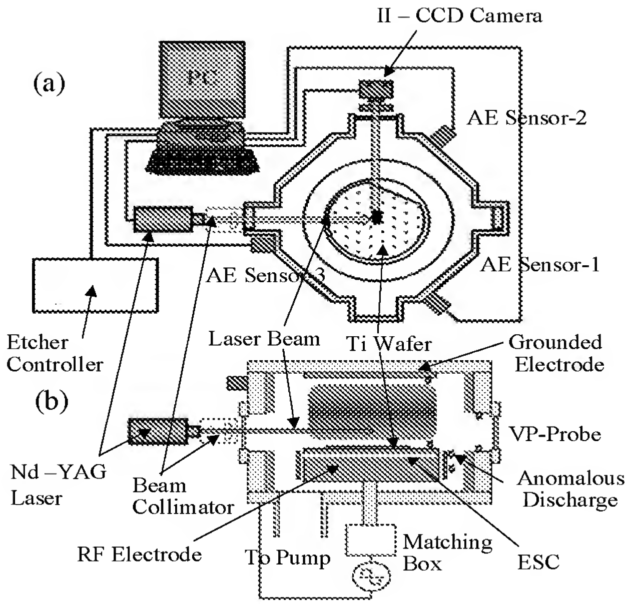

Fig. 1. Experimental setup for detecting anomalous discharge. The plasma equipment used was an RIE. The VP probes and AE sensors were attached to the chamber. The system also equipped with a particle monitoring system. (a) Top view of the particle monitoring system and the RIE chamber, (b) side view of the chamber.

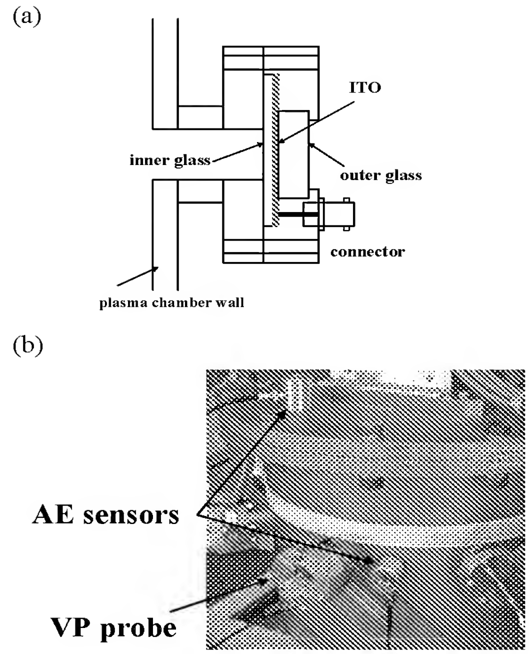

Fig. 2. (a) Schematic drawing of the cross section of the VP probe. (b) Photo showing VP probe and AE sensors attached to a plasma system. The plasma system in this photo is different from the RIE system used in this investigation.

the change in potential at the inner glass wall of the viewing port, was attached at the chamber of the RIE. The emission of supersonic waves due to anomalous discharges was detected as the reference using an AE sensor composed of piezoelectoric element (lead zirconate titanate). The AE sensor has the resonance frequency of 200 kHz. The AE sensor was attached on the top surface of the process chamber. Three AE detectors were attached respectively on the positions where external wall was approximately trisected. The experimental system was also equipped with an *in-situ* particle monitoring system which was originally developed [4,5]. The particle monitoring system was composed of a 523 nm second harmonic generation of ND-yttrium-aluminum-garnet pulse laser (2.5 W, 10 kHz, 70 ns full width at half maximums), an image intensified charge coupled device (CCD) camera, and a status-signal processor connected to the RIE. This system could detect larger than about 70 nm in diameter on Ti particles, and the detection limit was determined by plasma emission intensity. The image acquirement of laser light scattered by the particles was simultaneous with the status signals of the RIE, such as RF power, total pressure, process-gas flow rate, helium gas flow rate and ESC electric current.

Plasma was generated by supplying 13.56 MHz-excitation voltage. Anomalous discharges were induced by using Ti wafer with moisture under the following condition. The Ti wafers were mounted on the RF electrode by an electrostatic chuck (ESC) with helium backside cooling. The typical RF power supplied was 1000 W. Gas species were SF_6 and O_2. Discharge pressure was 30 Pa. The signals of the VP probe and the AE sensors were simultaneously monitored with a multiple-channel digital data recorder.

DETECTION OF ANOMALOUS DISCHARGE

Figures 2(a) shows schematic cross section of the VP probe of recent design. The transparent electrode film made of indium-tin oxide is placed in between the inner relatively-thin quartz-glass and the outer thick glass. In the original design, the transparent electrode was placed outside of a thick glass. The new probe was designed to improve the sensitivity by thinning the glass between the plasma and the electrode to increase the capacitive coupling between the plasma and the electrode. Figure 2(b) shows a photo of a VP probe mounted on a plasma system.

Figures 3(a) and 3(b) show the signal waveforms of the VP probe and the detection waveform of the AE sensor at an occurrence of anomalous discharge, respectively. While the VP probe is able to detect the change in plasma potential with the RF excitation signal [3], the RF component was filtered in the signal waveform shown in

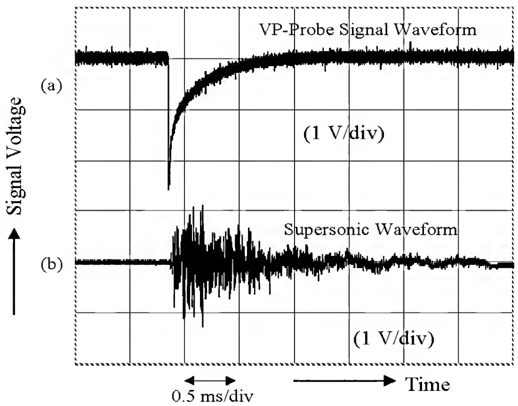

Fig. 3. Signal waveforms of (a)VP probe and (b)AE sensor detected in sync with an anomalous discharge.

Fig. 3(a). We can see that the VP-Probe detects the change in potential at the inner wall of the glass plate due to the anomalous discharge indicated by the AE sensor which detects the supersonic wave emitted from the anomalous discharge site. It is noteworthy that the signal in the VP probe appears slightly before the detection of the AE signal, which indicates the propagation delay of the AE wave along the chamber wall. The VP probe responds to the anomalous discharge with high sensitivity by giving a sharp minus output voltage. The signal of the VP probe exponentially decays with a time constant determined by the external circuit. Since the waveform of the VP-Probe shows RF-filtered signal, short events of 13.56 MHz-excitation frequency are not reflected to the output waveform.

The fact that the VP probe outputs signals responding to the RF excitation signal when the RF filtering is absent indicates that it detect the glass inner-wall potential determined by the electron diffusion from bulk plasma to the glass inner-wall. In other words, the VP probe detects the change in plasma potential. The fact that the VP probe outputs minus signal indicate that the flux of electron flow from the plasma increased at the moment of the occurrence of abnormal discharge. The output waveform of the VP-Probe suggests that a plasma state in which plasma density is higher or electron temperature is higher than the steady state is produced as a result of anomalous discharge in the RIE.

It is worthy to describe the qualitative behavior of the abnormal discharge which we observed in our experimental system. Anomalous discharges flickering all over the wafer stage and the interior wall surface of the chamber were observed through the VP probe. The flickering period of the anomalous discharge was once in about 3 seconds. It lasted for about 10 minutes and, then, faded away. But, when another wafers with moisture was put in the process chamber again, the anomalous discharge reoccurred at the same frequency as before. This phenomenon suggests that the adsorption onto the chamber interior wall surface of atmosphere component induce anomalous discharges. The particle generation was coincident with the signals of the VP probe and the AE sensor [3].

DETECTION OF FOESEEING SIGNAL AND ACTIVE SUPRESSION OF ABNORMAL DISCHARGE

We have found that the VP probe detects a small but definite signal prior to the occurrence of anomalous discharge. An example of the foreseeing signal is shown in Figure 4. The signal, which enables us to foresee the occurrence of anomalous discharge, appears a few to several tens millisecond before the first occurrence of a series of anomalous discharge. The presence of the foreseeing signal indicates that the plasma state slightly changes prior to the occurrence of the series of the abnormal discharges. For every case, the foreseeing signal gives positive signal which opposes to the signal detected at the occurrence of the abnormal discharge. This suggests that the electron density and/or electron temperature decreases before abnormal discharge takes place.

We have also found that the occurrence of abnormal discharge tends to be suppressed by reducing the voltage applied to the electrostatic chuck (ESC) of the wafer stage. Based on this fact, we have developed a electric feedback system which control the ESC voltage by using the foreseeing signal as the trigger. The system consisted of a digital to analog converter which controls the ESC voltage in addition to an electronic system which is able to record the abnormal discharge signals and to analyze the position of the abnormal discharge points.

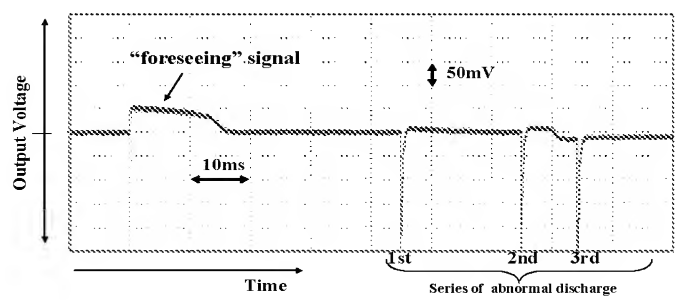

Fig. 4. Signal waveform of VP-Probe showing the "foreseeing" signal appears prior to a series of anomalous discharge.

Figure 5 shows an example of the effect of the active control. In the case where no control is applied (Fig. 5(a)), occurrence of a series of anomalous discharge following the foreseeing signal is clearly detected by both the VP

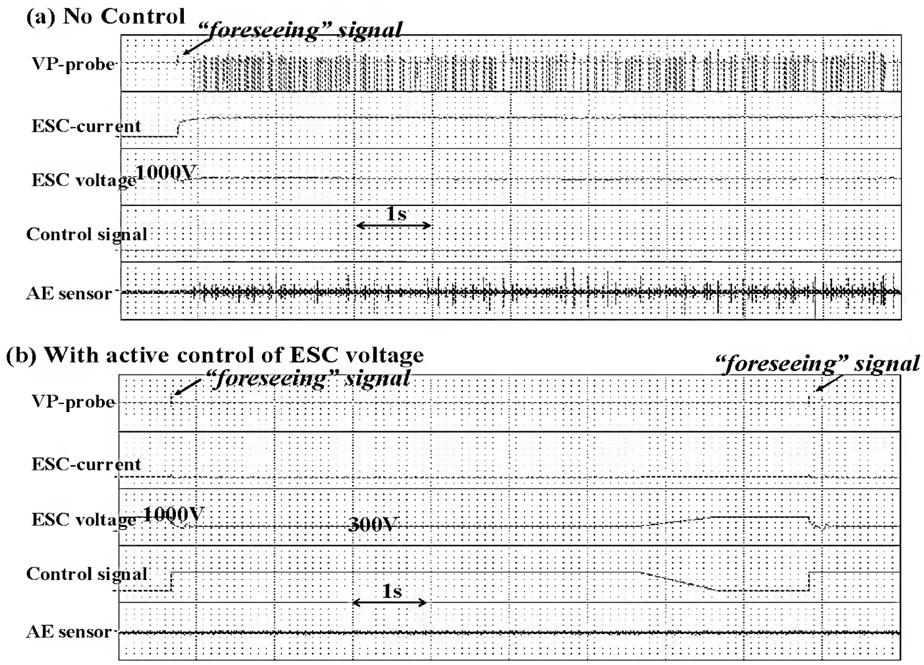

Fig. 5. Waveforms of signals showing the effect of the active control of electrostatic chuck (ESC) voltage. (a) When no control is applied, a number of anomalous discharge takes place. (b) When the ESC voltage control is carried out using the "foreseeing" signal as the trigger, anomalous discharge is completely suppressed.

probe and the AE sensor. On the other hand, in the case where the applied voltage of the electrostatic chuck is reduced by using the foreseeing signal as the trigger, anomalous discharge is completely suppressed and the plasma keeps steady state. It is noteworthy that the active control worked for two foreseeing signals observable in the VP probe signal shown in Figure 5(b).

CONCLUSION

The VP probe is able to detect the slight change in plasma state which occurs prior to the occurrence of abnormal discharge. This enables us to foresee the occurrence of the abnormal discharge. The time interval between the foreseeing signal and the occurrence of the abnormal discharge is several tens millisecond, which allows to build-up a electric system to control the plasma state. The active suppression of anomalous discharge is possible by controlling, for example, the applied voltage of electrostatic chuck of wafer stage. The work presented in this paper will greatly facilitate the development of "anomalous discharge free" environment to plasma processing of semiconductor manufacturing.

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